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Application of biomonitoring of air-suspended metal pollutants and enrichment factor analysis for source identification of metals from roadside in Phitsanulok municipality, Thailand

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ABSTRACT: Biomonitoring of air-suspended metallic pollutants using plants is an efficient and reliable technique. The enrichment factor (EF) is used to define how much the presence of metal elements in a sample is raised relative to the average natural abundance because of anthropogenic activities. This study performed a leaf-level holistic analysis of dust deposition on Thai bungor leaves. The EF was used for metal discrimination in terms of the natural and anthropogenic inputs to the system. Samples were exposed at ten roadside areas in Phitsanulok Municipality. Samples were collected for 15 days/month in March (dry season) and July (rainy season) 2022. Samples were analyzed for the content of 15 metals (Al, Ba, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, Pb, Sb, Sn, V, and Zn) by Inductively Coupled Plasma-Mass Spectrometer (ICP-MS). The results showed that Al, Na, Fe, and K constitute the major proportion of air pollutants. V was not found in either season. By EF analysis, Ba, K, and Na enrichment was minor ($1 < \mathrm{EF} \leqslant 3$), and Mg and Fe were moderately enriched ($3 < \mathrm{EF} \leqslant 5$), indicating that elements are influenced by human activities in addition to soil sources. Cr enrichment was severe ($10 < \mathrm{EF} \leqslant 25$), and the enrichment of Cd, Cu, Ni, Pb, Sb, Si, Sn, and Zn by anthropogenic activity was extremely severe ($\mathrm{EF} > 50$). This research will serve as a guideline for planning air quality management in Phitsanulok Municipality.

KEYWORDS: metal pollutants, atmospheric dust, enrichment factor, biomonitoring

INTRODUCTION

Metal contamination in road dust is an increasingly serious environmental problem in many countries [1, 2]. Road dust, a temporary sink for pollutants, is a sensitive indicator of metal contamination in urban environments [3]. Road dust has a complex composition that includes soil, deposited construction materials, airborne particulates, soot, and fumes discharged from industry and vehicles [4, 5]. The 2 distinct sources contributing to metal concentrations in the environment are the natural weathering of rocks and minerals, which is known as the background or crustal level, and metals derived from human activities [6, 7], e.g. industry [8, 9], transportation [10], biomass burning [11], mining and smelting [11], combustion of fossil fuel [11], and non-exhaust-derived pollutants from vehicles [12, 13]. Pollutant sources, composition, and distributions differ between cities, mainly depending on the city characteristics [14, 15]. Metals in road dust can be remobilized and transported into the atmosphere and soil through resuspension [1] and can easily enter the body through direct ingestion, inhalation, and dermal absorption [16]. People residing in communities that are 300 m away from a roadside or highway are liable to potentially toxic heavy metal pollution [17].

The enrichment factor (EF) is a widely used metric for determining how much the presence of an element in a sample has increased relative to the average natural abundance because of human activities [7]. The EF can be calculated by normalizing metal concentrations to an element that varies minimally in concentration with respect to a sample reference metal that does not vary because of geogenic or anthropogenic processes [17]. The EF has been employed as a tool to assess heavy metal contamination in various environmental media, e.g. road dust, airborne particulates, soil, and sediment [18–21].

Biomonitoring using plants is an efficient and reliable method for large-scale monitoring that complements expensive instrumental techniques to measure the impact of air-suspended metallic pollutants on air quality and the ecosystem [22].

The objective of this paper was to determine the metal species captured on leaves of Thai bungor trees (*Lagerstroemia loudonii* Teijsm. & Binn.) at 10 roadside areas in Phitsanulok Municipality, Thailand, between March (dry season) and July (rainy season) 2022 as an alternative method to those commonly used for determining atmospheric metal contamination. The samples were analyzed for the content of 15 metals (Al, Ba, Cd, Cu, Cr, Fe, K, Mg, Na, Ni, Pb, Sb, Sn, V, and Zn) by Inductively Coupled Plasma-Mass Spectrometer

(ICP-MS). In addition, the EF was used for element discrimination in terms of natural and anthropogenic inputs to the system.

MATERIALS AND METHODS

Study area and plant material

Phitsanulok province is in the lower northern region of Thailand, approximately 377 km north of Bangkok by road. Phitsanulok has 3 seasons: the "cold season" (December to January), "dry season" (February to May), and "rainy season" (June to October). In Thailand, especially in the northern region, high levels of pollution are observed from the beginning of the cold season until the end of the dry season. Samples were exposed at 10 roadside areas (T01–T10) in Phitsanulok Municipality, Thailand (Fig. 1). T01 is in Nai Mueang Subdistrict, at Phitsanulok Walking Street, which is open every Saturday from 5 pm to 10 pm. T02 is in Nai Mueang Subdistrict, in which the nature of the traffic flow requires frequent stop-start maneuvers. T03 is in Ban Khlong Subdistrict near intersections with heavy traffic in the evening and morning. T04 is in Phlai Chumphon Subdistrict and close to a four-lane road, connecting to nearby districts and Sukhothai province. T05 is in Hua Ro Subdistrict near intersections with heavy traffic in the evening and morning. T06 is in Nai Mueang Subdistrict, near intersections with heavy traffic in the evening and morning. T07 is in Nai Mueang Subdistrict, which is densely populated. T08 is located near a four-lane road, connecting to nearby districts and Phetchabun province. T09 and T10 are in Aranyik Subdistrict, near the railways.

The 60 cm tall Thai bungor tree was tested for its capacity to accumulate pollutants. Plants were planted in pots and placed on a plant stand to achieve a height of 150 cm above ground level to be at a height representing where humans breathe (Fig. 1). This method is similar to the standard test method for the collection and measurement of dustfall (settleable particulate matter) (ASTM D1739-98 (2017)) [23]. When it rained, volunteers moved the plants into shelter 24 h a day. Sampling point locations were recorded with Universal Transverse Mercator grid (UTM) positioning to log their Easting and Northing and the station number (Fig. 1).

Sample collection and preparation methods

The samples were collected from each site over 15 days/month [24] in March (dry season) and July (rainy season) 2022. The main reason for choosing March and July is based on historical data of PM2.5 and PM10 concentrations in Phitsanulok province from Thailand's air quality report in 2021 [25]. March had the highest levels of PM2.5 and PM10 and represents the dry season, while July had the lowest levels of PM2.5 and PM10 and was chosen to represent the rainy season.

After 15 days, the samples were taken back to the laboratory. Sample collections were performed using fresh disposable gloves for harvesting leaves from the petioles, avoiding contact with the leaf blade. The number of leaves collected for each tree varied according to the leaf size, to ensure that the total area of each sample was similar [24]. Leaves were cut from selected branches with plastic scissors, 4–6 leaves per plant (the total surface area is 150–200 cm^2). Upon collection, the leaves were placed in a clean plastic container [26]. Leaves with pests or diseases or damage were avoided [26]. The leaves in each sample were washed by filling the collection containers with 130 ml of Millipore-purified water, and then they were placed on a flatbed shaker for 1 h [24]. Leaves were rinsed with Millipore water, and the final volume of the wash solution was made up to 150 ml. The solution was divided into 2 75-ml plastic bottles for metal analysis. The second bottle is a spare.

Metal analysis

The 20 samples in both March and July were analyzed for metal concentrations at the Thailand Institute of National Science and Technology Development Agency Characterization and Testing Service Center (NCTC), an accredited national laboratory in Thailand. At the NCTC, the samples were analyzed by ICP-MS (ICPMS-2030 with LA-ICP-MS Software, Shimadzu, Japan) to determine the trace metal concentrations of Al, Ba, Cd, Cu, Cr, Fe, K, Mg, Na, Ni, Pb, Sb, Sn, V, and Zn.

Enrichment factor analysis for source identification of metals

The EF can differentiate between metals originating from human activities and those from natural processes to assess the degree of anthropogenic influence [7, 27, 28]. One such technique that is often applied uses normalization of a tested element against a reference [27, 28]. Generally, Fe, Al, Si, and Ti are used as reference elements because of their abundance in the Earth's crust [17–19, 29]. In this study, elemental Al was selected as the reference. The EF formula is represented by Eq. (1) [27, 30].

$$EF_{(X)} = \frac{x_{sample}/ref_{sample}}{x_{crust}/ref_{crust}} \qquad (1)$$

where x_{sample} is the concentration of the examined element in sample, ref_{sample} is the concentration of the reference element (Al) in the sample, x_{crust} is the content of the examined element in the Earth's crust, and ref_{crust} is the content of Al in the Earth's crust. The concentration of metals in the Earth's crust was obtained from Taylor and McLennan (1985) [31].

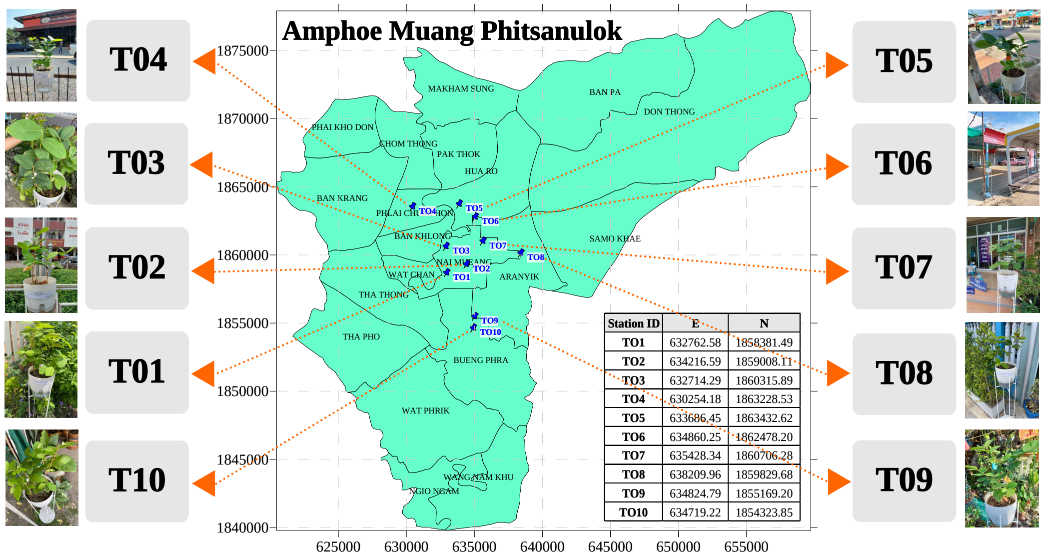

Fig. 1 The location of the 10 sampling sites and their coordinates.

RESULTS AND DISCUSSION

Metals concentration

The aim of this study was to examine the metal contaminations at the roadside in Phitsanulok Municipality, Thailand. The result showed that metals are enriched in road dust. The metal concentrations present on the leaves in March and July 2022 at 10 sites are presented in Figs. 2 and 3, and the average percentage contributions of 15 metals are illustrated in Figs. 4 and 5. Detailed results are illustrated in the supplementary data (Table S1 to Table S4). In summary, the greatest proportion of air pollutants was made up of Al, Na, Fe, and K in both seasons. Ba, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, Pb, Sb, Sn, V, and Zn were detected as minor elements. Vanadium was not detected. The detection of Cd, Cr, Cu, Fe, Ni, Pb, and Zn were associated with transportation emissions [32–34].

In March 2022, among the 10 stations, the highest concentrations of Al, Ba, Cu, Cr, K, and Zn were found in T01. Ni was highest in T02. Fe, Sb, and Sn were highest at T07. Cd and Pb were highest at T08. Mg and Na were highest at T09. Sb and V were not detected.

In July 2022, the highest concentrations of Al, Ba, Cd, K, Mg, Na, and Pb were found at T10. Cr and Fe were highest at T09. Ni, Sn, Zn were highest at T01, T03, T08, respectively. Cu, Sb, and V were not detected.

Accumulation of metals on leaves in March was higher than in July, which is attributed to March being significantly drier than July. In March, there were only 6 rainy days with an average relative humidity of 68% throughout the month, whereas July experienced a total of 17 rainy days and had a relative humidity of 98.71% [35].

Table 1 Contamination categories based on EF values [17, 34].

EF value	Definition
EF ⩽1	no enrichment
1< EF ⩽3	minor enrichment
3 < EF ⩽5	moderate enrichment
5 < EF ⩽10	moderately severe enrichment
10 < EF ⩽25	severe enrichment
25 < EF ⩽50	very severe enrichment
EF > 50	extremely severe enrichment

We also compared the metal contents of air-suspended metal pollutants found by biomonitoring and the metal contents of road dust from other locations (Table S5). The measured metals were generally lower than elsewhere, including Nakhon Ratchasima (Thailand), Singapore, Dhaka (Bangladesh), Soul (Korea), Tokyo/Osaka/Kyoto (Japan), Birmingham (England), Kavala (Greece), and several locations in China. However, the trends in the metal analysis results in Thailand were similar, for example, finding Fe in a relatively high concentration.

Enrichment factor analysis

The EF method was used to determine the impact of crustal metals and anthropogenic activities on metal pollution in the study area. The pollution categories that identify the sources of pollution are shown in Table 1. Tables 2 and 3 show the distribution of each element EF on the leaves in March and July 2022. We use different colors for each EF value to make it easier to analyze the results, i.e. EF ⩽1 (yellow), 1 < EF ⩽3

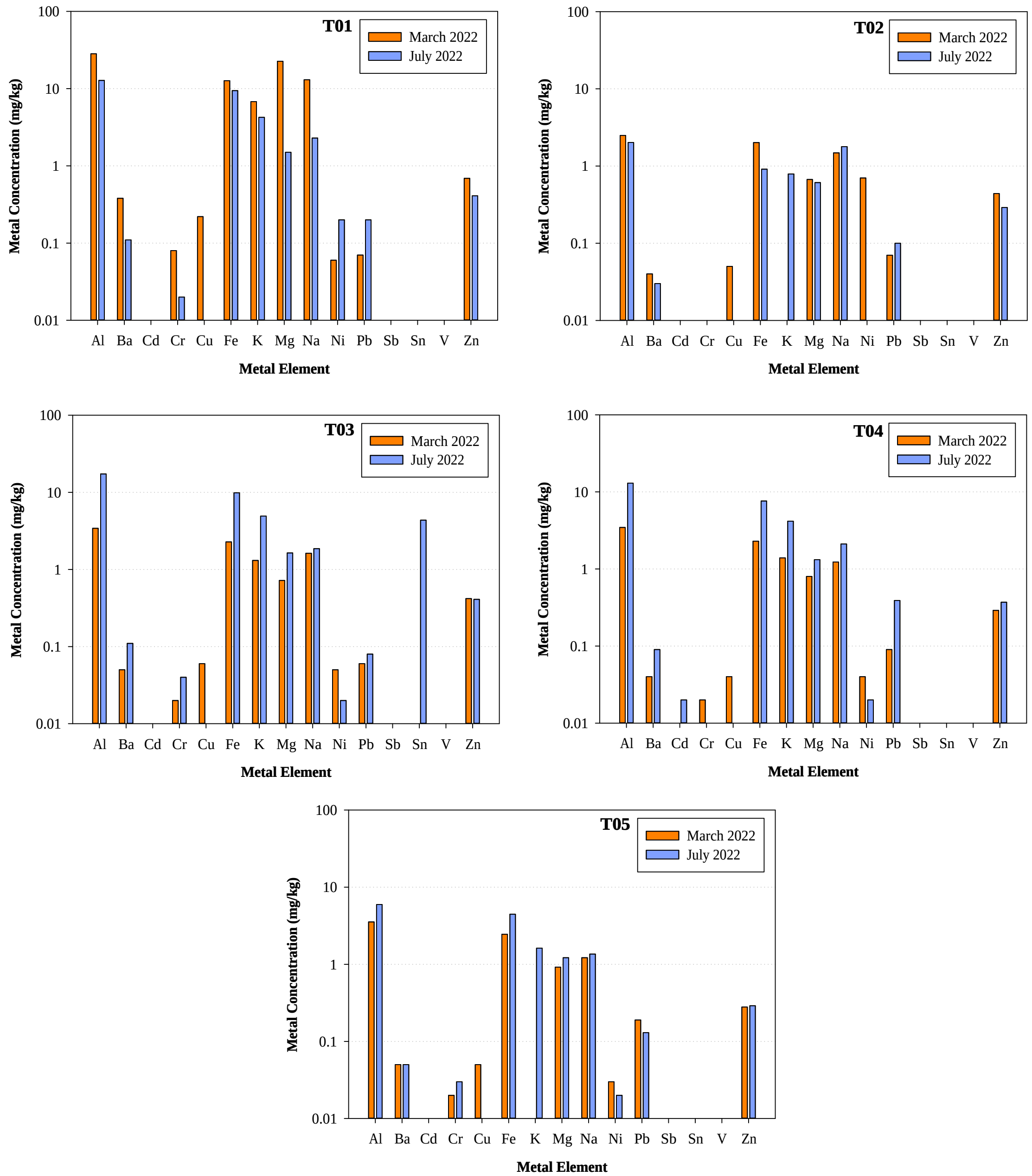

Fig. 2 Metal concentration on the leaves of the plant in March and July 2022 at T01–T05.

(green), 3 < EF ⩽5 (light blue), 5 < EF ⩽10 (light orange), 10 < EF ⩽25 (pink), 25 < EF ⩽50 (orange), and EF > 50 (red).

In March 2022, Ba, Fe, K, and Na enrichment was minor (1 < EF ⩽3), indicating that elements are influenced by human activities in addition to soil sources. Mg enrichment was moderately severe (5 < EF ⩽10), and Cr enrichment was severe (10 < EF ⩽25). The enrichment by anthropogenic activity of Cd, Cu, Ni, Pb, Sb, Si, Sn, and Zn was extremely severe (EF > 50). In July 2022, the EF analysis showed that Ba, K, Mg, and Na enrichment was minor (1 < EF ⩽3), while Fe enrichment was moderate (3 < EF ⩽5) and Cr enrichment was severe (10 < EF ⩽25). The enrichment of Cd, Ni, Pb, Sn, and Zn was extremely severe (EF > 50). Interestingly, no metals had an EF value ⩽1, which indicates that all metal pollutants were influenced by human activity and there was an anthropogenic impact on metal pollution in the Phitsanulok Municipality.

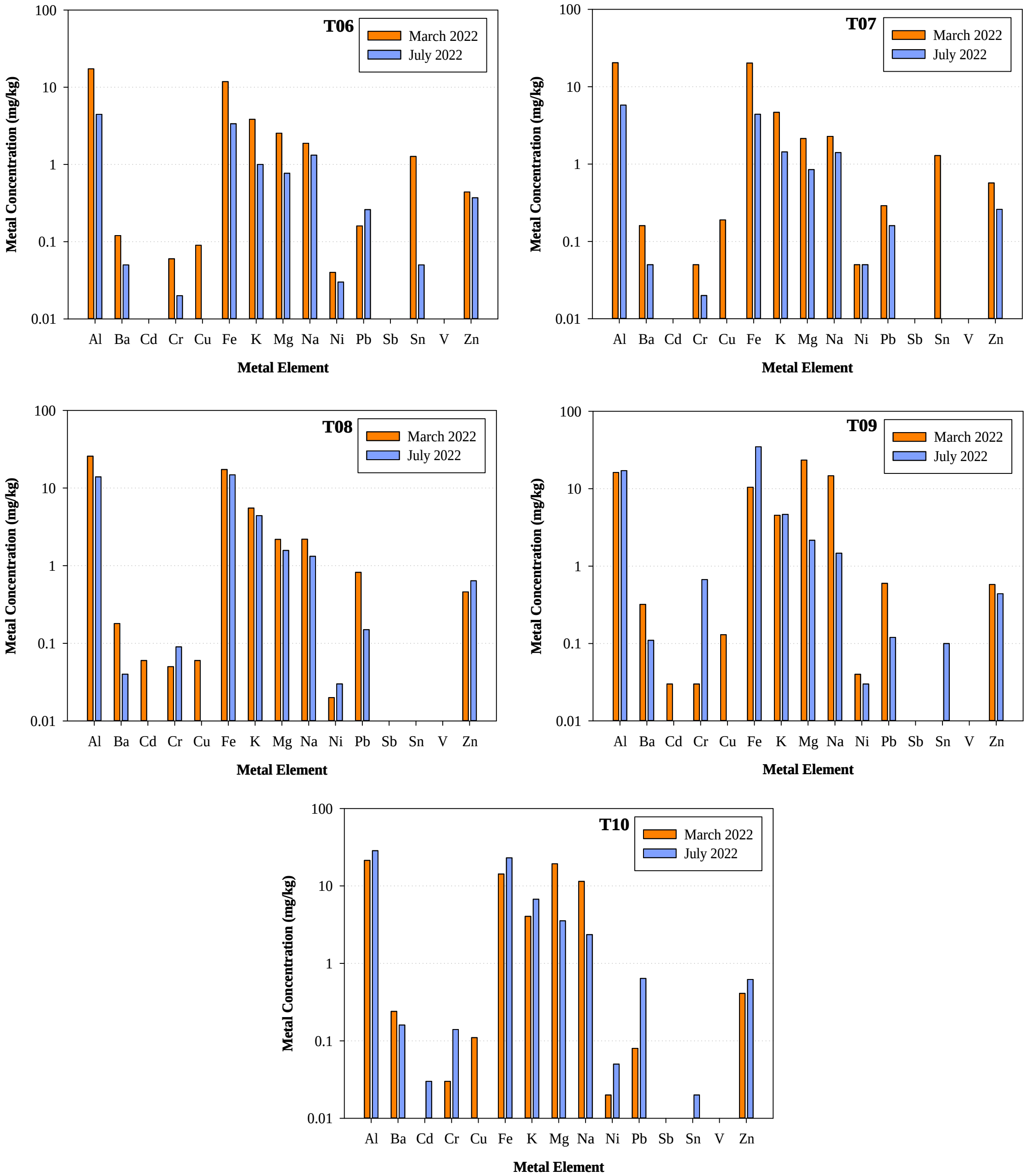

Fig. 3 Metal concentration on the leaves of the plant in March and July 2022 at T06–T10.

To summarize, EF is crucial for assessing environmental contamination and potential health risks. High EF typically indicate higher concentrations of metals, which can lead to adverse health effects such as cancer, neurological damage, lung damage, organ dysfunction, vomiting and diarrhea, high blood pressure, changes in heart rhythm or paralysis, and possible death [36]. For example, Cd (the EF value > 50) has been classified by IARC as carcinogenic (Group 1: Carcinogenic to humans) because of substantial evidence that Cd can cause lung cancer in both humans and animals exposed through inhalation [37]. Cd attached to airborne particles can travel great distances, partially dissolve in water, and adhere tightly to soil [38], and it is expelled slowly from the human body and accumulates mainly in the kidney [39]. Therefore, the findings of this study are an alarming sign for the safety of the environment in Phitsanulok Municipality.

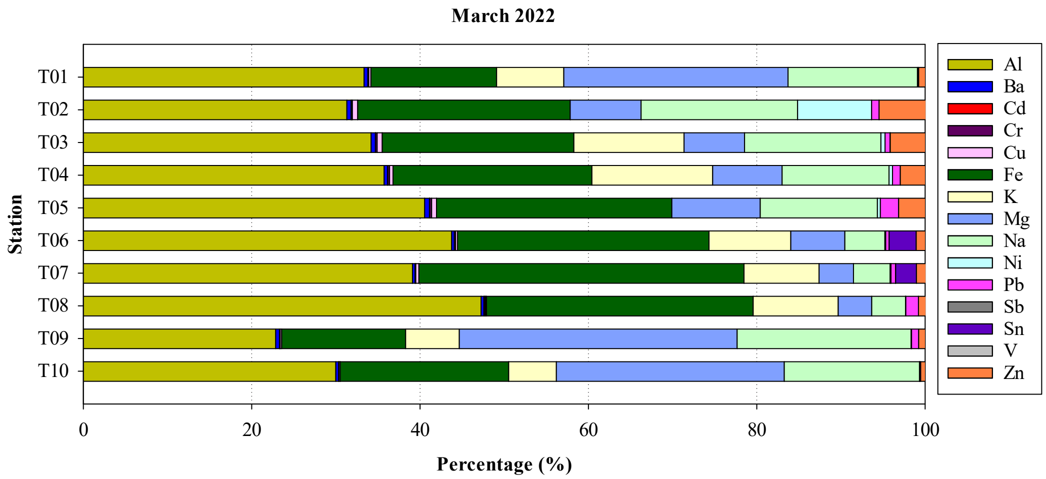

Fig. 4 The average percentage contribution of 15 metal elements in March 2022.

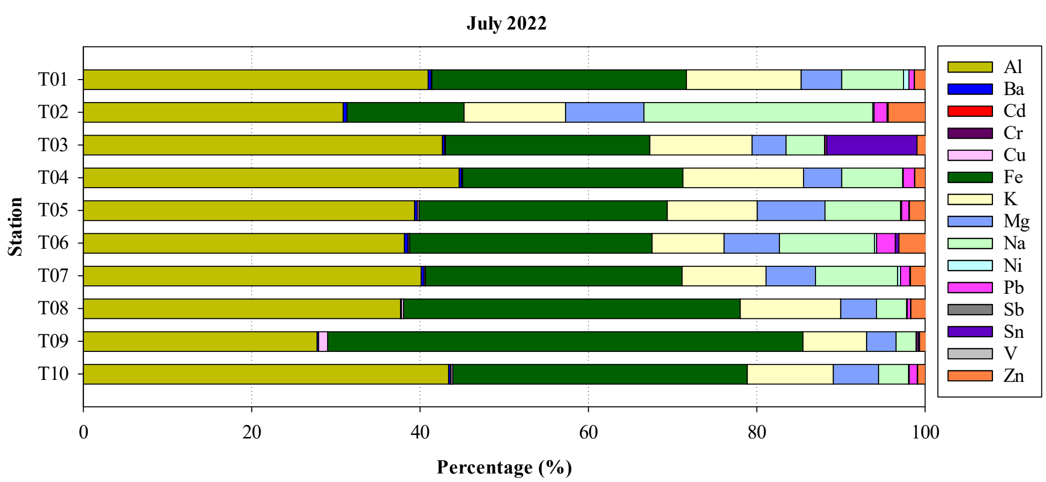

Fig. 5 The average percentage contribution of 15 metal elements in July 2022.

Table 2 The distribution of each element EF present on the leaves of the plant in March 2022.

Metal	EF value – March 2022									
	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10
Al*	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ba	1.96	2.35	2.14	1.69	2.06	1.01	1.14	1.02	2.88	1.64
Cd	102.30	879.71	297.46	524.02	628.59	197.28	106.21	1,907.19	1,515.53	105.57
Cr	6.49	9.23	13.43	13.28	12.94	7.97	5.61	4.45	4.24	3.22
Cu	24.99	64.58	56.42	37.18	45.30	16.73	29.85	7.48	25.74	16.55
Fe	1.03	1.85	1.53	1.52	1.59	1.57	2.27	1.54	1.48	1.53
K	0.69	0.00	1.10	1.15	0.00	0.64	0.66	0.61	0.80	0.54
Mg	4.83	1.63	1.27	1.40	1.57	0.89	0.63	0.51	8.74	5.46
Na	1.28	1.65	1.32	0.99	0.96	0.30	0.31	0.24	2.52	1.49
Ni	8.52	1,130.12	58.77	46.47	33.97	9.29	9.82	3.12	9.90	3.76
Pb	9.94	113.01	70.53	104.57	215.15	37.18	56.95	127.72	148.52	15.05
Sb	0.00	0.00	173.96	67.97	54.02	56.93	62.25	22.90	33.67	46.28
Sn	0.00	0.00	0.00	0.00	0.00	1,073.13	921.22	0.00	0.00	0.00
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	27.60	200.10	139.07	94.91	89.32	28.80	31.53	20.18	40.44	21.73

* Al is used as a reference element in this study.

Table 3 The distribution of each element EF present on the leaves of the plant in July 2022.

Metal	EF value — July 2022									
	T01	T02	T03	T04	T05	T06	T07	T08	T09	T10
Al	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ba	1.26	2.17	0.93	1.01	1.23	1.64	1.26	0.42	0.94	0.82
Cd	208.80	0.00	0.00	1,263.14	0.00	739.47	136.78	0.00	0.00	859.97
Cr	3.60	0.00	5.30	1.77	11.56	10.30	7.92	14.86	89.90	11.24
Cu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe	1.70	1.03	1.31	1.35	1.72	1.74	1.75	2.44	4.68	1.85
K	0.96	1.12	0.82	0.92	0.78	0.64	0.71	0.91	0.78	0.68
Mg	0.71	1.83	0.57	0.61	1.24	1.04	0.89	0.68	0.76	0.75
Na	0.50	2.45	0.30	0.45	0.63	0.82	0.68	0.26	0.24	0.23
Ni	62.96	19.90	4.64	6.19	13.49	27.04	34.66	8.67	7.04	7.02
Pb	62.96	199.01	18.56	120.69	87.68	234.35	110.90	43.35	28.18	89.90
Sb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sn	8.15	72.37	3,681.12	11.25	24.53	163.88	25.20	10.51	85.39	10.22
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	36.36	162.57	26.79	32.25	55.10	93.94	50.76	52.10	29.10	24.53

* Al is used as a reference element in this study.

CONCLUSION

Biomonitoring of air-suspended metallic pollutants and EF analysis was an effective tool for source identification of metals in 10 study areas in Phitsanulok Municipality, Thailand, in March (dry season) and July (rainy season) 2022. The leaves of the Thai bungor tree can accumulate air-suspended metallic pollutants. The EF analysis distinguished between metals naturally abundant and those derived from anthropogenic activities. The study of metal elements and their concentrations in road dust found that 14 out of 15 were present. Al, Na, Fe, and K made up the major proportion of air pollutants, while V was not found in this study. The EF analysis showed that metal pollution is influenced by human activities as there were no samples where the EF value $\leqslant 1$. The enrichment of Cd, Ni, Pb, Sn, and Zn by anthropogenic activity was extremely severe (EF > 50).

Appendix A. Supplementary data

Supplementary data associated with this article can be found at https://dx.doi.org/10.2306/scienceasia1513-1874.2025.012.

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Appendix A. Supplementary data

Table S1 Metal concentration present on the leaves of the plant in March 2022 (Unit: mg/kg).

No.	Metal	Station										Min	Max	Avg.	SD
		TO1	TO2	TO3	TO4	TO5	TO6	TO7	TO8	TO9	TO10				
1	Al	28.31	2.490	3.420	3.460	3.550	17.30	20.47	25.81	16.24	21.37	2.49	28.31	14.24	9.59
2	Ba	0.380	0.040	0.050	0.040	0.050	0.120	0.160	0.180	0.320	0.240	0.04	0.38	0.16	0.12
3	Cd	0.004	0.003	0.001	0.002	0.003	0.004	0.003	0.060	0.030	0.003	0.00	0.06	0.01	0.02
4	Cr	0.080	0.010	0.020	0.020	0.020	0.060	0.050	0.050	0.030	0.030	0.01	0.08	0.04	0.02
5	Cu	0.220	0.050	0.060	0.040	0.050	0.090	0.190	0.060	0.130	0.110	0.04	0.22	0.10	0.06
6	Fe	12.68	2.010	2.280	2.290	2.450	11.82	20.24	17.32	10.47	14.26	2.01	20.24	9.58	6.52
7	K	6.790	0.000	1.310	1.390	0.000	3.840	4.670	5.520	4.540	4.050	0.00	6.79	3.21	2.25
8	Mg	22.62	0.670	0.720	0.800	0.920	2.540	2.140	2.180	23.48	19.30	0.67	23.48	7.54	9.41
9	Na	13.05	1.480	1.620	1.230	1.220	1.880	2.280	2.190	14.70	11.46	1.22	14.70	5.11	5.27
10	Ni	0.060	0.700	0.050	0.040	0.030	0.040	0.050	0.020	0.040	0.020	0.02	0.70	0.11	0.20
11	Pb	0.070	0.070	0.060	0.090	0.190	0.160	0.290	0.820	0.600	0.080	0.06	0.82	0.24	0.25
12	Sb	0.000	0.000	0.001	0.001	0.000	0.002	0.003	0.001	0.001	0.002	0.00	0.00	0.00	0.00
13	Sn	0.000	0.000	0.000	0.000	0.000	1.270	1.290	0.000	0.000	0.000	0.00	1.29	0.26	0.51
14	V	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
15	Zn	0.690	0.440	0.420	0.290	0.280	0.440	0.570	0.460	0.580	0.410	0.28	0.69	0.46	0.12

Table S2 Metal concentration present on the leaves of the plant in July 2022 (Unit: mg/kg).

No.	Metal	Station										Min	Max	Avg.	SD
		TO1	TO2	TO3	TO4	TO5	TO6	TO7	TO8	TO9	TO10				
1	Al	12.77	2.020	17.33	12.99	5.960	4.460	5.800	13.91	17.12	28.62	2.02	28.62	12.10	7.53
2	Ba	0.110	0.030	0.110	0.090	0.050	0.050	0.050	0.040	0.110	0.160	0.03	0.16	0.08	0.04
3	Cd	0.003	0.000	0.000	0.020	0.000	0.004	0.001	0.000	0.000	0.030	0.00	0.03	0.01	0.01
4	Cr	0.020	0.000	0.040	0.010	0.030	0.020	0.020	0.090	0.670	0.140	0.00	0.67	0.10	0.19
5	Cu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
6	Fe	9.430	0.910	9.870	7.620	4.470	3.370	4.410	14.78	34.85	23.09	0.91	34.85	11.28	9.95
7	K	4.250	0.790	4.940	4.170	1.620	1.000	1.440	4.410	4.660	6.740	0.79	6.74	3.40	1.92
8	Mg	1.500	0.610	1.640	1.320	1.220	0.770	0.850	1.570	2.160	3.550	0.61	3.55	1.52	0.81
9	Na	2.290	1.780	1.860	2.110	1.360	1.320	1.410	1.320	1.470	2.350	1.32	2.35	1.73	0.39
10	Ni	0.200	0.010	0.020	0.020	0.020	0.030	0.050	0.030	0.030	0.050	0.01	0.20	0.05	0.05
11	Pb	0.200	0.100	0.080	0.390	0.130	0.260	0.160	0.150	0.120	0.640	0.08	0.64	0.22	0.16
12	Sb	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
13	Sn	0.007	0.010	4.364	0.010	0.010	0.050	0.010	0.010	0.100	0.020	0.01	4.36	0.46	1.30
14	V	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00
15	Zn	0.410	0.290	0.410	0.370	0.290	0.370	0.260	0.640	0.440	0.620	0.26	0.64	0.41	0.12

Table S3 The arithmetic average percentage contribution of 15 metal elements in March 2022 (Unit: %).

No.	Metal	Station										Min	Max	Avg.	SD
		TO1	TO2	TO3	TO4	TO5	TO6	TO7	TO8	TO9	TO10				
1	Al	33.32	31.27	34.16	35.70	40.51	43.72	39.06	47.21	22.82	29.96	22.82	47.21	35.77	6.77
2	Ba	0.45	0.50	0.50	0.41	0.57	0.30	0.31	0.33	0.45	0.34	0.30	0.57	0.42	0.09
3	Cd	0.00	0.03	0.01	0.02	0.03	0.01	0.01	0.11	0.04	0.00	0.00	0.11	0.03	0.03
4	Cr	0.09	0.13	0.20	0.21	0.23	0.15	0.10	0.09	0.04	0.04	0.04	0.23	0.13	0.06
5	Cu	0.26	0.63	0.60	0.41	0.57	0.23	0.36	0.11	0.18	0.15	0.11	0.63	0.35	0.18
6	Fe	14.93	25.24	22.77	23.63	27.96	29.87	38.62	31.68	14.71	19.99	14.71	38.62	24.94	7.09
7	K	7.99	0.00	13.08	14.34	0.00	9.71	8.91	10.10	6.38	5.68	0.00	14.34	7.62	4.57
8	Mg	26.63	8.41	7.19	8.25	10.50	6.42	4.08	3.99	33.00	27.06	3.99	33.00	13.55	10.33
9	Na	15.36	18.59	16.18	12.69	13.92	4.75	4.35	4.01	20.66	16.07	4.01	20.66	12.66	5.82
10	Ni	0.07	8.79	0.50	0.41	0.34	0.10	0.10	0.04	0.06	0.03	0.03	8.79	1.04	2.59
11	Pb	0.08	0.88	0.60	0.93	2.17	0.40	0.55	1.50	0.84	0.11	0.08	2.17	0.81	0.60
12	Sb	0.00	0.00	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00
13	Sn	0.00	0.00	0.00	0.00	0.00	3.21	2.46	0.00	0.00	0.00	0.00	3.21	0.57	1.15
14	V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Zn	0.81	5.53	4.20	2.99	3.20	1.11	1.09	0.84	0.82	0.58	0.58	5.53	2.12	1.65

Table S4 The arithmetic average percentage contribution of 15 metal elements in July 2022 (Unit: %).

No.	Metal	Station										Min	Max	Avg.	SD
		TO1	TO2	TO3	TO4	TO5	TO6	TO7	TO8	TO9	TO10				
1	Al	40.94	30.84	42.62	44.61	39.31	38.11	40.11	37.65	27.73	43.36	27.73	44.61	38.53	5.12
2	Ba	0.35	0.46	0.27	0.31	0.33	0.43	0.35	0.11	0.18	0.24	0.11	0.46	0.30	0.10
3	Cd	0.01	0.00	0.00	0.07	0.00	0.03	0.01	0.00	0.00	0.05	0.00	0.07	0.02	0.02
4	Cr	0.06	0.00	0.10	0.03	0.20	0.17	0.14	0.24	1.09	0.21	0.00	1.09	0.22	0.30
5	Cu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Fe	30.23	13.89	24.27	26.17	29.49	28.79	30.50	40.00	56.46	34.98	13.89	56.46	31.48	10.54
7	K	13.63	12.06	12.15	14.32	10.69	8.54	9.96	11.94	7.55	10.21	7.55	14.32	11.10	2.02
8	Mg	4.81	9.31	4.03	4.53	8.05	6.58	5.88	4.25	3.50	5.38	3.50	9.31	5.63	1.77
9	Na	7.34	27.18	4.57	7.25	8.97	11.28	9.75	3.57	2.38	3.56	2.38	27.18	8.59	6.80
10	Ni	0.64	0.15	0.05	0.07	0.13	0.26	0.35	0.08	0.05	0.08	0.05	0.64	0.19	0.18
11	Pb	0.64	1.53	0.20	1.34	0.86	2.22	1.11	0.41	0.19	0.97	0.19	2.22	0.95	0.61
12	Sb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Sn	0.02	0.15	10.73	0.03	0.07	0.43	0.07	0.03	0.16	0.03	0.02	10.73	1.17	3.19
14	V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Zn	1.32	4.43	1.01	1.27	1.91	3.16	1.80	1.73	0.71	0.94	0.71	4.43	1.83	1.09

Table S5 Metal distribution in street dusts of different cities (mg/kg).

Country	City	Al	Ba	Cd	Cr	Cu	Fe	K	Mg	Na	Ni	Pb	Sb	Sn	V	Zn	Reference
Thailand	Phitsanulok	14.24	0.16	0.01	0.04	0.1	9.58	3.21	7.54	5.11	0.11	0.24	0	0.26	0	0.46	This study (Mar 2022)
	Phitsanulok	12.10	0.08	0.01	0.10	0	11.28	3.4	1.52	1.73	0.05	0.22	0	0.46	0	0.41	This study (Jul 2022)
	Phitsanulok	–	–	24.7	–	67.7	6,315.1	–	–	–	–	62.3	–	–	–	322.1	[1]
	Nakhon Ratchasima	–	–	1.42	78.36	96.99	11,528	–	–	–	–	1,126.6	–	–	–	781.93	[2]
	Sukhothai	–	–	8	–	3	37,064	–	–	–	–	245	–	–	–	1,140	[3]
Singapore	–	–	–	0.3	73.2	97.7	–	–	–	–	10.3	111.3	–	–	–	619.7	[4]
Bangladesh	Dhaka	–	–	–	107	47	–	–	–	–	25.4	75.2	–	–	–	151.7	[5]
Korea	Seoul	–	–	–	151	396	–	–	–	–	–	144	–	–	–	795	[6]
Japan	Tokyo	–	–	1.40		–	–	–	–	–	43	264	–	–	–	2,200	[7]
	Osaka	–	–	1.04	73.9	–	–	–	–	–	19	229	–	–	–	1,070	[7]
	Kyoto	–	–	1.03	35.1	–	–	–	–	–	76.7	156	–	–	–	2,250	[7]
England	Birmingham	–	–	1.62	197.9	467	–	–	–	–	41.1	48	–	–	–	534	[8]
Greece	Kavala	–	–	0.2	–	124	–	–	–	–	58	301	–	–	–	272	[9]
Chaina	Shijiazhuang	–	–	1.86	131.70	91.06	–	–	–	–	40.99	154.78	–	–	–	496.17	[6]
	Xi'an	–	–	–	177.5	46.6	–	–	–	–	29.3	97.4	–	–	–	169.2	[10]
	Beijing	–	–	0.72	84.7	69.9	–	–	–	–	25.2	105	–	–	–	222	[11]
	Changchun	–	–	0.62	95.98	68.4	–	–	–	–	–	93.6	–	–	–	465.35	[12]
	Lanzhou	–	–	–	62.14	72.97	–	–	–	–	–	62.25	–	–	–	296.92	[13]
	Wuhan	–	–	–	75.30	32.10	–	–	–	–	27.7	102.6	–	–	–	224.2	[14]
	Shanghai	–	–	1.23	159	197	–	–	–	–	84	295	–	–	–	734	[15]
	Chengdu	–	–	4.40	114	244	–	–	–	–	88.1	375	–	–	–	1,117	[15]

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